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ORIGINAL RESEARCH

Assessment of visual selective and orienting attention with a new touchscreen tablet-based test in school-aged children: Pilot study

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Abstract

Background: Selective attention and visuospatial orienting attention are important cognitive functions for children's development. Testing based on touch-based mobile technology platforms is becoming increasingly widespread in psychological assessment. **Objective:** The aim of the study was to investigate the reliability and validity of the newly developed touchscreen tablet-based test of selective and orienting attention (t-SOA test) in typical developing children aged 7–10 years. **Methods:** Two age groups of children, the group$_{7–8}$ (7–8 years, 9 girls, 10 boys) and the group$_{9–10}$ (9–10 years, 9 girls, 9 boys), performed the t-SOA test on a tablet (Android operating system) and a stylus, as well as the Reaction test of selective attention of the Vienna Test System (RT4-VTS). The criterion validity of the t-SOA test was verified by the RT4-VTS, and the construct validity via an analysis of the effect of age on the results of the t-SOA test. The reliability of the t-SOA test was assessed through internal consistency. **Results:** The internal consistency of the response time (RT) to the target stimulus was demonstrated to be excellent, Cronbach's α = .944. The mixed linear model with two factors – the central and the spatial (peripheral) cues, showed no significant effect on mean RT. Mean RT, median RT, and the coefficient of variation for RTs (CVRT) in the t-SOA test correlated significantly with analogous test scores of the RT4-VTS test, but not in the case of the number of correct responses, omissions, and commissions. A statistically significant effect of the age group was found for mean RT, median RTs, CVRT, and omission of the t-SOA test. **Conclusions:** The study demonstrated that the newly constructed t- SOA test may be a valid and reliable tool for assessing the level of visual selective attention of children during middle childhood. The study supported the current suggestion that the assessment of cognitive functions with a touchscreen tablet and a digital stylus is feasible and accepted by school-age children.

Keywords: attention, reaction test, tablet computer, orienting, development, children

Introduction

Selective attention, together with tonic and sustained attention, is considered the main component of attention (Schuhfried, 2011). Selective attention involves directing cognitive resources to relevant objects or events while suppressing or ignoring irrelevant elements (Bater & Jordan, 2019; Murphy et al., 2016). It also incorporates the scope within which task-relevant contextual information is utilized. Cognitive selection may be advantageous for more efficient and faster information processing (Coch et al., 2005) and encoding (Markant et al., 2015). These processes may run under voluntary, intentional (top-down), or automatic (bottom-up) control (Proctor & Vu, 2023).

In most human activities, selective attention is related to the processing of visual stimuli. Visual selective attention involves directing cognitive resources to relevant stimuli in a visual scene, ignoring irrelevant stimuli, and suppressing disturbing or competing information (Lueck & Dutton, 2015). This type of selective attention provides the basis for visual perception (Katsuki & Constantinidis, 2014) and is, therefore, considered a critical cognitive ability for learning (Astheimer et al., 2014) and the development of self-regulation and executive functions in children (Posner et al., 2014; Rothbart et al., 2011).

Selective attention skills develop throughout childhood (Fisher, 2019). Immature selective attention in younger children is characterized by a tendency to divide attention more broadly, as well as to attach it to other contextual information (Waszak et al., 2010). The attentional tendencies are reflected in slower information processing, whereas the attachment of further contextual stimuli may support learning from both target and non-target information (Plebanek & Sloutsky, 2017). Nevertheless, compared to younger children, more efficient selected attention has been found in older children, probably as a consequence of reduced cognitive stress with increasing age and, thus, less distraction by irrelevant stimuli or the development of executive functioning (Brodeur & Pond, 2001). In late childhood, individuals manifest a substantial improvement

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in filtering visual information in various cognitive tasks, including those involving visual selection (Hanania & Smith, 2010).

Neuropsychological testing of visual selective attention is useful both for assessing the cognitive maturation of children and screening potential attention disorders. In children with ADHD and dyslexia, deficits in visual selective attention have been reported, indicated by longer and less accurate responses (Hokken et al., 2023).

Visual selective attention may precede or be associated with visuospatial orienting attention by directing cognitive resources toward relevant stimuli in the visual field. This cognitive ability comprises a covert shift of cognitive resources to a spatially cued location (Liu et al., 2013) and incorporates engaging, disengaging, and shifting attention (Posner & Petersen, 1990). The neurophysiological differences between orienting attention and selective attention may be considered. The ability to orient or reorient attention is considered a function of the orienting attention network (Posner & Petersen, 1990), whereas selective attention is associated with the functioning of the executive network (Lackner et al., 2013; Posner et al., 2014). Some researchers presuppose a different developmental trajectory for the orienting and executive attention networks. Whereas executive cognitive functions and selective attention are stabilized during late childhood and adolescence (e.g., Boen et al., 2020; Fisher, 2019; Hanania & Smith, 2010), the development of some aspects of orienting attention is already stabilized at around the age of ten, such as the shift of attention to exogenous signals (Pozuelos et al., 2014), while other aspects such as disengaging from an invalid cue location and reorienting visual attention to a valid location are not perfected until late childhood (Pozuelos et al., 2014). Selective and visuospatial orienting attention are important areas for children's cognitive development, including their learning capacity. These two components of attention can be combined or integrated into tasks in real environments. Therefore, this study aimed to develop and verify a selective attention test that would simultaneously enable the assessment of visually oriented attention using modern touchscreen tablet technology.

Touch-based mobile technology platforms, such as tablets, have the potential to replace desktop computers in the testing of cognitive functions because of their easier access to children and increased effectiveness of test delivery, scoring, and reporting (Chernyshenko & Stark, 2015). However, researchers also mention the possible risks of tablet-based testing, such as individual variability in children's technical familiarity and acceptance, physical factors related to the test itself (Jenkins et al., 2016), the possible need for special adjustments or modifications to minimize device-related layout differences, and possible distraction by functions unrelated to the test, such as voice-controlled instructions or picture feedback (Ling, 2016). Therefore, our study aimed to, within the framework of developing our touchscreen tablet-based test of selective and orientation attention (t-SOA test), verify its reliability and validity in typical developing children aged between seven and ten. We investigated these basic psychometric qualities based on the following assumptions: First, if the t-SOA test is valid, the measures of selective and visuospatial orienting attention should reflect cognitive improvement with the increasing age of the children. This hypothesis is based on knowledge of the development of the executive and orienting attention networks during childhood (Konrad et al., 2005; Waszak et al., 2010). Concurrently, we did not assume any differences in the measures of the t-SOA test between girls and boys as there was no clear evidence of sex variation in either component of attention during middle childhood. Furthermore, we investigated the criterion validity of the t-SOA test in relation to the Reaction Test of the Vienna Test System (VTS), which is a standardized neuropsychological tool (Schuhfried, 2011). To address the reliability of the test, we investigated the internal consistency of the t-SOA test.

Methods

Participants

For the study, 37 child participants (18 girls and 19 boys), with an age range of 7.0–10.9 years and mean age 8.7 ± 1.5 years, formed 2 groups consisting of younger children aged 7–8 years (group$_{7–8}$: n = 19, 9 girls, 10 boys) and older children aged 9–10 years (group$_{9–10}$: n = 18, 9 girls, 9 boys). The participants were randomly selected from a mainstream public school that provides education according to the National Framework Educational Programme for Elementary Schools. They were selected according to the following inclusion criteria: (a) age between 7.0 and 10.9 years and (b) right-hand preference defined by the writing hand. The exclusion criteria were (c) autism spectrum disorder; (d) ADHD; (e) learning disorders; (f) hearing impairment; (g) non-corrected visual impairment; (h) psychotic, behavioral and/or neurological disorders; (i) functional disability of upper limbs; (j) use of drugs affecting attention; and (k) acute mental and/or physical discomfort such as problems with sleeping in the night before testing, a feeling of mental or physical fatigue, and the manifestation of anxiety. Preliminary analysis confirmed no significant difference in age between the girls and boys throughout the entire sample, $F(1, 33) = 0.696$, $p = .548$, and separately in the younger and older age groups, $F(1, 15) = 0.900$, $p = .427$ and $F(1, 14) = 0.431$, $p = .455$. An a priori power analysis demonstrated that the sample size $N = 38$ would be sufficient to identify a significant effect of age, sex, and order on tests by using an analysis of variance with a power of $(1 – \beta) = .85$, $\alpha = .05$ and Cohen's $f = .50$. Cohen's $f \geq .40$ is considered a large effect size (Cohen, 1988).

Written informed consent was obtained from the legal guardians of the participating children. Verbal consent was also obtained from the school management and each participant prior to his/her participation in the test.

The tests presented the children with game-like tasks on a desktop computer and touchscreen tablet. The psychologist, research assistants, and children were unaware of the research purpose. Ethical approval for the study was obtained from the Review Board of the Technology Agency of the Czech Republic, code TL 03000219.

Measures

The t-SOA test

The construction of the t-SOA test was based on a methodological approach to selective attention as processes of differentiation and filtering of target stimuli from non-target stimuli (e.g., Brickenkamp et al., 2014; Schuhfried, 2011). To assess visuospatial orienting attention, this approach was combined with the paradigm of central and spatial (valid) cue trials (Fan et al., 2002; Rueda et al., 2004).

The t-SOA test comprised 48 trials divided into 2 identical consecutive blocks (Table 1). The participant held a stylus in the start position on a white circle (diameter 21 mm) located at the center of the lower part of the screen and fixed their eyes on a specific point in the shape of the red letter X at the center of the screen. A central (neutral) cue (blue star, diameter 16 mm) appeared in the middle of the screen, or a peripheral (valid) cue (blue star) on the left or right side of the screen, always with a duration of 250 ms. The central cues and the left and right peripheral cues appeared in a ratio of 2:1:1 across trials with both target and non-target stimuli. The cues appeared 3000 or 5000 ms after the offset of the position of the previous stimulus.

A visual stimulus (a circle, diameter 16 mm) appeared 400 and 700 ms after the cue on the right and left side of the screen, respectively. If a peripheral cue appeared, the following stimulus appeared on the same side. Upon the appearance of a target stimulus (blue and yellow circles appearing simultaneously), the participant responded as quickly as possible by lifting the stylus from the start position and tapping it on a black circle (diameter 32 mm) located on the side on which the target stimulus appeared (Figure 1). The display of the target stimulus remained until a response was detected for a maximum of 1000 ms. After this response, the participant immediately returned the stylus to the white circle, where they held the stylus and again looked at the specific point in the middle of the screen.

The non-target stimuli that appeared were either a yellow circle, a blue circle, two yellow circles, or two blue circles (duration 1000 ms), either on the left or right side of the screen. The target and non-target stimuli appeared throughout the entire task at a ratio of 1:2, and each type of stimulus appeared on the left and right sides at a ratio of 1:1.

Two blocks of test trials were preceded by one block of eighteen practice trials in a ratio of 1:2 (target:non-target stimuli), with locations on the left and right sides in a 1:1 ratio for both types of stimuli. The central/right/left cue ratio was identical in both blocks of test trials. The duration of the test trials was approximately 4 min 30 s; all tests included instructions and practice trials for eight minutes.

The test software measures the following scores:

(i, ii) MRT_{TAB} and $MdnRT_{TAB}$ – mean and median response time (RT) on a target stimulus (RT is measured as the interval between the moment of appearance of the target stimulus and the moment the stylus left the start position);

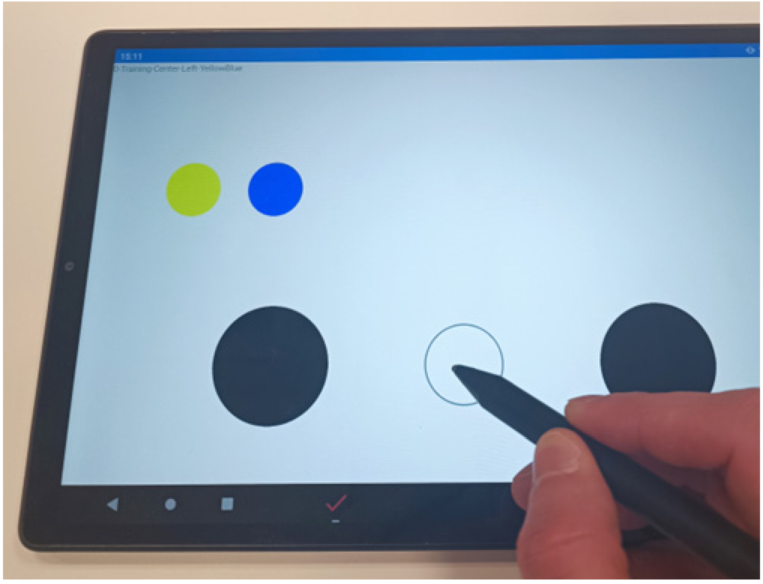
(iii, iv) $CVRT_{TAB}$ and $SDRT_{TAB}$ (variation coefficient and standard deviation of RTs);

(v, vi) MRTcen, MRTper (mean RT at target trials with the central and peripheral cues, respectively);

Table 1 The scheme of the t-SOA test

Trial	Type of stimulus	Location of stimulus	Location of warning signal	Interval between warning signal and stimulus
First block				
1	yellow-yellow	left	central	700
2	blue-blue	left	peripheral left	700
3	target (yellow-blue)	right	central	400
4	blue-blue	left	central	400
5	target (yellow-blue)	right	peripheral right	700
6	blue	right	central	400
7	yellow-yellow	right	peripheral right	400
8	target (yellow-blue)	left	central	700
9	blue	right	peripheral right	400
10	yellow	right	peripheral right	700
11	blue-blue	right	central	700
12	target (yellow-blue)	left	central	400
13	yellow	left	peripheral left	400
14	target (yellow-blue)	right	central	700
15	blue	left	peripheral left	700
16	yellow-yellow	left	peripheral left	700
17	blue-blue	right	peripheral right	400
18	yellow-yellow	right	central	400
19	target (yellow-blue)	left	peripheral left	700
20	target (yellow-blue)	right	peripheral right	400
21	yellow	right	central	700
22	blue	left	central	700
23	target (yellow-blue)	left	peripheral left	400
24	yellow	left	central	400
Second block				
25–48	the same scheme as the first block			

Figure 1 The screen at the moment the target stimulus has appeared



(vii) orientRT$_{TAB}$ (difference between MRTcen and MRTper);¨

(viii) CorrResp$_{TAB}$ (number of correct responses to a target stimulus), (ix) omission$_{TAB}$ (number of no-responses to the target stimulus), and (x) comission$_{TAB}$ (number of responses to the non-target stimulus).

The test application for Android operating systems was created as a multiplatform mobile tool that was optimized for a tablet with a larger touchscreen. Consequently, we used Microsoft Xamarin.Forms technology with ASP.NET Core (Microsoft, Redmond, WA, USA). Animation of the events was run on a frequency of 60 Hz and the frequency of data capture was 100 Hz in the t-SOA test. The test was graphically independent of the number of parameters; thus, running the test did not affect the evaluation of the test values. The results were stored asynchronously in a database placed in Azure Cloud Services (Microsoft, Redmond, WA, USA) using an interface program application developed by the authors.

Reaction Test of the Vienna Test System

A standardized Reaction Test, Form 4 of the VTS, version 8 (RT4-VTS test; Schuhfried GmbH, Mödling, Austria) was used to assess selective attention (Schuhfried, 2011). This computer-based hand-eye reaction test consisted of 48 trials with 5 types of stimuli: the target stimulus – yellow circle with a concurrent red circle (16 times) – and the non-target stimulus – red circle (4 times), yellow circle (12 times), red circle with concurrent tone (8 times), and single tone (8 times). Thus, the ratio of the presented target and non-target stimuli was 1:2. All circle stimuli had a diameter of 2 cm and were displayed in the center of the black background on a computer screen. The tone stimulus was a stereo sound with a frequency of 2000 Hz lasting 500 ms.

From the basic position of the index finger of the preferred hand on the home button (diameter 2 cm), the participant responded to the target stimulus as quickly as possible by pressing the rectangular black response button (5.5 × 1.5 cm) on the operating panel. After responding, the participant placed their index finger back on the home button to adopt the basic position. RT was measured as the interval between the moment the target stimulus appeared and the moment the index finger left the home button. The target stimulus remained displayed until a response was detected up to a maximum of 1500 ms. The stimuli were presented in inter-stimulus intervals of 1.5 s, 2.5 s, or 4.0 s. Before the test trials, the participant performed nine practice trials. The total test duration was 9 min.

The following test scores were assessed: mean RT as a measure of selective attention (MRT), Box-Cox transformed standard deviation of RTs (SDRT), and coefficient of variation of RT (CV RT; %) as measures of the intra-individual variability of attention, number of omissions (no responses to the target stimulus), and number of commissions (responses to non-target stimuli). The following incorrect responses were identified by the VTS software and were not included in the calculation of the variables:

(i) concurrent pressing of the home and response buttons with two different fingers;

(ii) using a finger other than the index finger to press the response button, as indicated by an interval of < 50 ms between lifting the index finger off the home button and pressing the response button;

(iii) lifting the finger off the home button before the stimulus appeared.

Excellent reliability measured as internal consistency (Cronbach's α = .900) for the RT4-VTS test was reported (Schuhfried, 2011). If the calibration of time measurement is performed in the Vienna Test System for a specific configuration of the computer system, the RT measurement is very precise, whereas, in the non-calibrated form of the test, there is a maximum of 2% technical errors of RTs (Schuhfried, 2011).

Procedure

The participants performed both tests in a quiet room at their school between 8:30 and 11:30 a.m. The rest interval between the tests lasted for 20 min. The order of the tests was counterbalanced for each age group. Each participant performed both tests while sitting comfortably at a table on a chair with their elbows/arms resting on the table. The height of the chair was adjusted for each participant such that their knees formed an approximately 90º angle. The t-SOA test was performed on a tablet Lenovo Tab M10 FHD (Lenovo, Hong Kong, China) with a 10.3 inches (~82.2% screen-to-body ratio) IPS LCD screen of 330 nits at the resolution of 1920 × 1200 pixels (~220 ppi density), using a Dicota Active Stylus Premium D31260 stylus (Dicota, Pfäffikon, Switzerland). The tablet was placed flat on the table in front of the participant at a comfortable distance to enable them to place their forearms on the table and move the stylus along the tablet's touchscreen. An examiner sat beside the participants and presented the test as a computer game to encourage them. After a brief motivational interview, the examiner commenced the test. The test app automatically provided the participants with instructions and demonstrations, followed by practice trials with feedback before the test trials began.

To perform the RT4-VTS test, a VTS response panel with buttons was placed 5 cm from the edge of the table. An IBM-compatible laptop computer with an Intel i7 processor and a 15-inch screen with a 1920 × 1020 resolution was located close to the response panel. The participants viewed the screen from a distance of 52 cm. The examiner provided brief instructions and descriptions of the procedures. The participants were, then, provided with a computer-driven practice of the test task accompanied by written instructions on the screen. The practice block contained nine trials, of which five were with a target stimulus and the remainder with one of the four types of non-target stimuli. The computer test program provided the participants with visual feedback if they committed an error. After the practice session, the examiner asked the participants whether they understood the task fully. There was a 90-s break between the practice and test blocks. During the tests, no feedback or encouragement was provided to the participants. The examiners and the participants were blinded to the test performance results.

Data analysis

The Shapiro-Wilk test was used to verify the assumption of normal data distribution. The reliability of the t-SOA test was examined by Cronbach's α internal consistency coefficient, based on correlations between 16 RTs on the target stimulus in the "target" trials, that is, the test items. To identify the target items that violated the internal consistency of the test, Cronbach's α coefficients were calculated for all combinations of the set of 15 target items (RTs) after excluding 1 item. Although presenting an identical task, the target items differed according to the type of cue – eight central and peripheral cue items, respectively. To test the effect of cue location on the MRT score, we used a mixed linear model in which the cue location was a fixed effect and had two values. To examine the criterion validity of the t-SOA test, the metric SOA scores were correlated with the analogous scores of the RT4-VTS test using Pearson's correlation coefficients. Polyserial and polychoric correlation coefficients and standard errors of these coefficients were calculated to examine the relationship between discrete SOA scores and analogical scores on the RT4-VTS test.

To reveal the effects of age ($group_{7–8}$ vs. $group_{9–10}$), sex (boys vs. girls), and order of test administration (1st vs. 2nd order) on the t-SOA test scores with a normal distribution, a *t*-test was used. The effect size by Cohen's *d* was calculated, with the interpretation $d = 0.2, 0.5$, and 0.8, as small, medium, and large effects, respectively (Cohen, 1988). For test scores with non-normal distribution (MRT_{TAB}, $SDRT_{TAB}$, $CVRT_{TAB}$), the effects of age, sex, and test order were examined using the Mann-Whitney *U* test. The effect size was calculated as a ratio of standardized *U* test statistics ($|z|$) and the square root of the number of observations, with the interpretation $r < .3$, .3–.5 and > .5 as small, medium, and large effects, respectively (Cohen, 1988).

The scores $CorrResp_{TAB}$ and $omission_{TAB}$ presented discrete variables with a dominant portion of the values 16 and 0, respectively. Therefore, each of the two scores was transformed into a binary score with two categories, namely 16 and < 16 for $CorrResp_{TAB}$ and 0 and > 0 for $omission_{TAB}$. Then, the effects of age, sex, and test order on these two scores were examined using Pearson's χ^2 test 2 (two levels of age, sex, or test order; see above) × 2 (two categories of the binary test score). Due to the small sample size, Yates' continuity correction of the Pearson χ^2 statistic was conducted. The phi (ϕ) coefficient was calculated as a measure of the association between age, sex, or test order and the test score $CorrResp_{TAB}$ and $omission_{TAB}$, respectively. The effects of age, sex, and test order on the $comission_{TAB}$ were not examined, as this score included a very small number of non-null values and was, thus, very close to a constant. Data analyses were performed with IBM SPSS Statistics (Version 28.0; IBM, Armonk, NJ, USA).

Results

Reliability of the t-SOA test

The descriptive statistics of the tests are presented in Table 2. The internal consistency of the RTs (test items) was demonstrated to be excellent, with Cronbach's coefficient α = .944 and .939–.944 after the exclusion of each RT from the set of 16 target items. In addition, the results of the mixed linear model with two factors, the central and the spatial (peripheral) cues, showed no significant effect on mean RT across all target items, $t(569) = 1.106$, $p = .269$, $SE = 6.297$, with a trivial effect size of 0.002.

Validity of the t-SOA test

MRT_{TAB}, $MdnRT_{TAB}$, and both scores of the variability of RTs – $CVRT_{TAB}$ and $SDRT_{TAB}$ – correlated significantly with analogous test scores in the criterion for the RT4-VTS test (Table 3), in contrast to the non-significant correlations of the number of correct responses, omissions, and commissions to the same scores of the RT4-VTS test (Table 3).

The analysis demonstrated a statistically significant effect of the age group (7–8 years vs. 9–10 years) on the MRT_{TAB}, $MdnRT_{TAB}$, $CVRT_{TAB}$, $SDRT_{TAB}$, and $omission_{TAB}$ of the t-SOA test (Table 4). The indicators of orienting attention, orientRT, and the number of correct responses ($CorrResp_{TAB}$) were not significantly different between the two age groups (Table 4).

The scores of the t-SOA test did not differ significantly between girls and boys ($MdnRT_{TAB}$ = 584 ± 105 vs. 561 ± 93 ms, p = .512; MRT_{TAB} = 564 ± 89 vs. 560 ± 97 ms, p = .685; $CVRT_{TAB}$ 20.9 ± 14.2 vs. 17.3 ± 11.6%, p = .518; $SDRT_{TAB}$ = 118 ± 79 vs. 96 ± 59 ms, p = .499; orientRT = 15.3 ± 44.7 vs. 14.5 ± 46.5 ms, p = .957) and median (*Mdn*) and interquartile range (IQR) for the number of correct responses ($CorrResp_{TAB}$), *Mdn* (IQR) = 14.5 (13–16) vs. 15 (12–16), p > .99, ϕ = .019, and the number of omissions *Mdn* (IQR) = 1 (0–1) vs. 0 (0–1), p = .611, ϕ = –.138.

The effect of the order of performance of the t-SOA and RT4-VTS tests was not significant for $MdnRT_{TAB}$, p = .155; MRT_{TAB}, p = .180; $CVRT_{TAB}$, p = .730; $SDRT_{TAB}$, p = .461; $orientRT_{TAB}$, p = .217; $CorrResp_{TAB}$, p = .061; and $omission_{TAB}$, p = .611.

Discussion

The individual's capability for visuospatial orienting of attention was indicated by the orienting effect ($orientRT_{TAB}$), which was identified as the difference in the RT in target trials of peripheral and central cues (Fan et al., 2002; Rueda et al., 2004). The central cue constituted a non-predictive alert signal, around which a peripherally located stimulus triggered a shift in attention from the fixation point to the area of the peripheral stimulus. This shift in attention may be underpinned by a reflexive, automatic orienting mechanism (Johnson et al., 2020) and, thus, evaluates the exogenous orientation of spatial attention (Enns & Brodeur, 1989). In contrast with this, the peripheral valid cue in the predictive conditions triggers a shift in the individual's attention from the fixation point to this cue into an area where the future stimulus appears. This situation may trigger voluntary endogenous orientation (shift) of spatial attention, which involves internal expectations and strategies to subsequently process information (Enns & Brodeur, 1989; Johnson et al., 2020). This approach to orienting attention used for the t-SOA test

Table 2 Results of the t-SOA test in the sample

Parameter	*M* ± *SD*	
MRT_{TAB} (ms)	562 ± 93	
$MdnT_{TAB}$ (ms)	573 ± 100	
$CVRT_{TAB}$ (%)	19.2 ± 13.1	
$SDRT_{TAB}$ (ms)	107 ± 71	
MRTcen (ms)	577 ± 115	
MRTper (ms)	575 ± 79	
$orientRT_{TAB}$ (ms)	14.9 ± 45.6	
$CorrResp_{TAB}$ (*n*)	13.6 ± 3.3	85.0 ± 20.6%
$omission_{TAB}$ (*n*)	1.0 ± 1.7	6.3 ± 10.6%
$commission_{TAB}$ (*n*)	0.1 ± 0.3	0.3 ± 0.9%

Note. The scores of the t-SOA test: $MRTRT_{TAB}$, $MdnRT_{TAB}$ = median and mean of reaction times (RTs); $CVRT_{TAB}$ and $SDRT_{TAB}$ = variation coefficient and standard deviation of RTs; MRTcen, MRTper = mean RT on target stimuli preceded by a central and peripheral warning signal (WS), respectively; $orientRT_{TAB}$ = difference between medians of RTs on a target stimulus preceded by central WS and peripheral WS; $CorrResp_{TAB}$ = a number of correct responses.

Table 3 Correlations between the scores of the t-SOA test and the RT4-VTS test

Correlated test scores	Type	Coefficient	*p*
$MdnRT_{TAB}$ – MRT	Pearson	.684	< .001
MRT_{TAB} – MRT	Pearson	.495	.002
$CVRT_{TAB}$ – CVRT[a]	Pearson	.417	.013
$SDRT_{TAB}$ – SDRT	Pearson	.397	.015
$orientRT_{TAB}$ – MRT	Pearson	.245	.143
$CorrResp_{TAB}$ – CorrResp	polyserial	.253	.156
$omission_{TAB}$ – omission	polychoric	.536	.165
$commission_{TAB}$ – commission	polychoric	–.790	.979

Note. The scores of the t-SOA test: $MdnRT_{TAB}$ and MRT_{TAB} = median and mean of reaction times (RTs); $CVRT_{TAB}$ and $SDRT_{TAB}$ = variation coefficient and standard deviation of RTs; $orientRT_{TAB}$ = difference between two medians of RTs on a target stimulus preceded by central warning signal (WS) and peripheral WS; $CorrResp_{TAB}$ = a number of correct responses. The scores of the RT4 VTS test: MRT = mean of RTs; CVRT and SDRT = variation coefficient and standard deviation of RTs; CorrResp = a number of correct responses. [a]2 out of 37 observations excluded due to extreme values (higher than Q3 + 3*IQR).

Table 4 Results of the t-SOA test in the age groups and the effect of the age group on the scores of the test

Parameter	7–8 year group	9–10 year group	*t*	*p*	Cohen's *d*	
$MdnRT_{TAB}$ (ms)	647 ± 86	493 ± 33	7.143	< .001	2.35	
$SDRT_{TAB}$ (ms)	149 ± 79	63 ± 16	4.566	< .001	1.50	
MRT_{TAB} (ms)	623 ± 92	498 ± 29	41.0	< .001	0.65	
$CVRT_{TAB}$ (%)	25.3 ± 15.7	12.6 ± 3.3	74.0	.003	0.49	
orientRT (ms)	26.0 ± 50.6	3.2 ± 36.1	121.0	.134	0.25	
			χ^2	*p*	ϕ	*p*
$CorrResp_{TAB}$ (*n*)	4–15 in 16 part.	4–15 in 9 part.				
	16 in 3 part.	16 in 9 part.	3.499	.061	.365	.026
$omission_{TAB}$ (*n*)	1–7 in 14 part.	1–7 in 3 part.				
	0 in 5 part.	0 in 15 part.	12.099	.002	–.572	.001

Note. $MdnRT_{TAB}$ and MRT_{TAB} = median and mean of reaction times (RTs); $CVRT_{TAB}$ and $SDRT_{TAB}$ = variation coefficient and standard deviation of RTs; $orientRT_{TAB}$ = difference between two medians of RTs on a target stimulus preceded by central warning signal (WS) and peripheral WS; $CorrResp_{TAB}$ = a number of correct responses. *t, U*, χ^2 = test statistic for the *t*-test, Mann-Whitney *U* test and Pearson's chi-squared, respectively; Cohen's *d, r*, ϕ = measures of effect size for the particular statistics tests used; part. = participants.

differs somewhat from the evaluation of endogenous and exogenous orienting attention based on a comparison of RTs attained in valid vs. invalid cue trials under predictive and non-predictive conditions, respectively (Johnson et al., 2020; Leclercq & Siéroff, 2013).

The activation of endogenous orienting attention may be supported by a longer interval between the cue and stimulus, referred to as stimulus onset asynchrony (SOAsy; Müller & Findlay, 1988). In the t-SOA test, we used SOAsy of 400 and 700 ms. Querne et al. (2009), in a cohort of children of identical age as in our study, demonstrated that the visual alert signal triggers phasic attention, indicated by a shortening of RT at an SOAsy of 100 ms in comparison with RT without a warning signal, but this does not apply to longer SOAsy of 450 and 800 ms. The SOAsy used in the t-SOA test, therefore, appears to be appropriate for reducing the influence of phasic attention, and the RT in trials with a peripheral predictive cue reflected dominantly endogenous orienting of attention.

The results demonstrated excellent internal consistency across all target trials in the t-SOA test. In addition, the time required for information processing in the target trials did not depend on whether the target stimulus was cued spatially or centrally. These results strongly indicate that across all the target trials, RT was predominantly determined by a single latent factor, and they also showed very good reliability of cognitive-motor responses in children in a selective task performed on a tablet.

The above-mentioned findings, as well as the positive orienting effect on only 59.6% of the children (average 14.9 ms, Table 2), raise the question of why the RT in the spatially cued target trials, as an indicator of endogenous spatial orientation, was not significantly shorter than in the central (neutral) cue trials. One possible explanation is that some children may prefer the inhibition of inappropriate responses to a warning cue, likely to compensate for the immature differentiation of a cue and target stimulus in a rapid sequence (Psotta et al., 2021). Consequently, the peripheral predictive cues may not have sufficiently stimulated the endogenous orientation of attention to the cued space in time. It would be possible to indicate the very rare occurrence of incorrect responses (on average, 0.9% of all non-target trials) and simultaneously, the greater number of errors of omission (10.6% on average) or failure to respond within 1000 ms as a preference for inhibiting inappropriate responses (to the non-target stimulus). Second, top-down control of attention in younger children may not be sufficiently developed due to the maturation of the prefrontal cortex throughout childhood (Casey et al., 2000); thus, the functioning of the endogenous orientation of attention may be limited. Furthermore, some studies based on the paradigm of valid versus invalid cues demonstrated that, in addition to the endogenous orientation of attention, in 6–10-year-old children, there may be a simultaneous improvement in the distribution of attention to less probable events (Leclercq & Siéroff, 2013). Developing a divided allocation of attention may also have partially contributed to the reduction in the difference in the speed of information processing in the spatially and neutral-cued trials of the t-SOA test.

Mean and median RT across all target trials (MRT_{TAB} and $MdnRT_{TAB}$), as scores of selective attention, demonstrated a close relationship with the indicator of selective attention – MRT – in the RT4-VTS test. It is possible to explain the stronger determination of $MdnRT_{TAB}$ than MRT_{TAB} by MRT (r^2 = .468 vs. .245) as the median of RTs is a more objective measure of central tendency than that of non-normal data, as is the case in intra-individual RTs in reaction and attention tasks (e.g., Dykiert et al., 2012; Schuhfried, 2011), including selective attention tasks (Spieler et al., 2000).

$SDRT_{TAB}$ and $CVRT_{TAB}$ as scores of intra-individual variability in response times were significantly correlated with the scores of variability in the RT4-VTS test. The higher criterion validity of $CVRT_{TAB}$ than $SDRT_{TAB}$ is probably because the CV is related to the individual mean RT and may, therefore, be a "purer" indicator of the variability of cognitive processes.

Compared to 7–8-year-old children, 9–10-year-old children manifested a shorter response time in the t-SOA test; simultaneously, their responses were less variable in terms of time. These findings support the validity of the t-SOA test, as age-related differences in cognitive performance in the selective attention task could reflect developmental changes in cognition. According to the dual-stage two-phase model of selective attention, this component of attention includes an early stage in which information is selected by perceptual filters whose selectivity is relatively limited and a late stage with abruptly increased and more efficient selection of stimuli (Hübner et al., 2010). In accordance with the cognitive model of information processing (Schmidt et al., 2018), this first stage is related to stimulus detection and recognition. These processes increase their effectiveness as measured by RTs in simple and selective reaction tasks throughout childhood and adolescence (Dykiert et al., 2012). According to some researchers, the development of selective attention to objects (the second stage) has a protracted course into late childhood (Booth et al., 2003; Hanania & Smith, 2010). This is reflected in the slow maturation of the basic neural architecture important for selective attention, which is reflected in functional changes in both selective attention and executive control throughout childhood and adolescence (Mullane et al., 2016; Stevens & Bavelier, 2012).

The number of correct responses ($CorrResp_{TAB}$), $omission_{TAB}$, and $commission_{TAB}$ in the t-SOA test, which constitutes secondary information in clinical-psychological testing (e.g., Schuhfried, 2011), did not demonstrate criterion validity for the same type of scores in the RT4-VTS test. This was primarily because of the extremely abnormal distribution of the discrete scores as a majority of children performed the test tasks without any errors. Consequently, the transformation of these scores into binary variables (see Data analysis) cannot avoid the distortion of information.

The scores on the t-SOA test were not dependent on sex. A review of the present investigation by Li et al. (2021) suggests that sex differences in both executive and orienting attention remain unclear. The validity of the results of the study was supported by the finding that the cognitive performance on the t-SOA was not significantly impaired by the order in which the children performed both tests.

A potential limitation of the present study was its small sample size. In addition, the t-SOA test does not involve invalid cues; therefore, subprocesses of orienting attention, such as disengagement and reorienting, were probably not involved in the performance of the test. However, the primary aim of the t-SOA test is to assess visual selective attention and visuospatial orienting of attention in children.

Conclusions

In summary, we have shown that the newly constructed t-SOA test may be a valid and reliable tool for assessing the level of visual selective attention of children during middle childhood. The results of this pilot study indicate that the ability to orient attention, evaluated by performance in a selective attention task and the use of the spatial predictive–central (neutral) cue paradigm, may be task-specific. For broader use of the t-SOA test, it is necessary to verify its relationship with specific tests that identify endogenous and exogenous attention as well as to investigate the interaction of visual selective attention and orienting attention in future research. The study supported the current suggestion that the assessment of cognitive functions with a touchscreen tablet and a digital stylus is feasible and accepted by children in middle childhood.

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Conflict of interest

The authors report no conflict of interest.

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